



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Designing with living organisms

Citation for published version:

Moisy, A & Pschetz, L 2017, Designing with living organisms. in *Proceedings of Research Through Design Conference RTD'17*. RTD'17, RTD, Research Through Design (RTD) Conference 2017, Edinburgh, United Kingdom, 22/03/17. <https://doi.org/10.6084/m9.figshare.4746994.v1>

Digital Object Identifier (DOI):

[10.6084/m9.figshare.4746994.v1](https://doi.org/10.6084/m9.figshare.4746994.v1)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Proceedings of Research Through Design Conference RTD'17

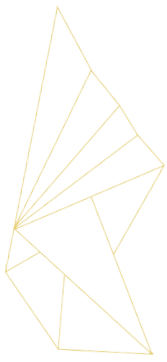
General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.





Designing with Living Organisms

Anaïs Moisy¹, Larissa Pschetz²

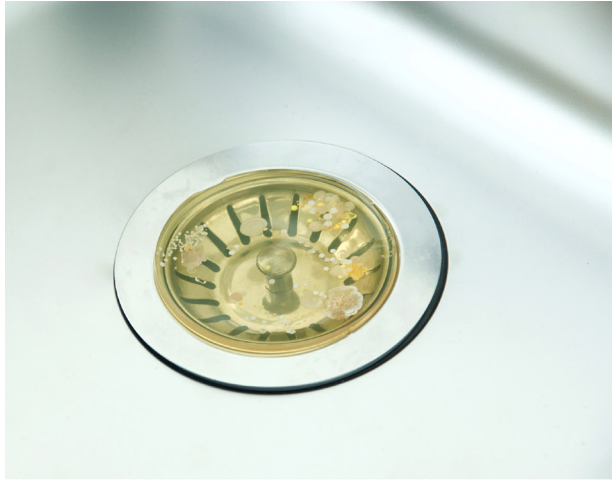
¹ University of Edinburgh, Edinburgh, Scotland
amoisy@exseed.ed.ac.uk, anais.moisy@me.com

² University of Edinburgh, Edinburgh, Scotland
L.Pschetz@ed.ac.uk

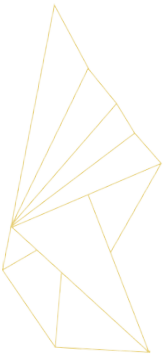
Keywords: BioDesign; Synthetic Biology; Designing with Life

Abstract: Recent advances in biology and intersecting areas of research have brought a renewed interest in engaging with living materials. BioDesign is becoming increasingly popular, and has included diverse proposals, ranging from products that incorporate microorganisms as new, often considered more sustainable materials, to speculations on future impact of synthetic biology. In this paper we present three objects that incorporate living organisms as a way to reflect on the design process. We discuss how engaging with living materials could be considered a shift in traditional design practices, and the challenges of integrating design in current biotechnology development.





Anaïs Moisy , Larissa Pschetz | Designing with living organisms





Introduction

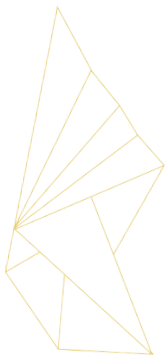
From biomimetics to bionics and the integration of natural materials, Design has long engaged with biology-related themes. Facing pressing environmental and social issues, as well as new developments in micro, systems and synthetic biology, this engagement has recently gained new characteristics (Antonelli, 2012, Ginsberg et al. 2014). Designers are increasingly looking at biological sources in search of alternative, more sustainable materials, through products such as the BioBrick by Ginger Dossier, which utilises bacteria to fuse sand particles in order to reduce CO₂, or conceptual projects such as the Microbial Home by Philips Design, which presents an organic system that ‘digests’ domestic waste. At the same time, synthetic biology builds momentum (Cameron et al. 2014) promising to change industrial practices, the way we manipulate living organisms (Ginsberg et al. 2014), and understand life (Johung, 2016; Calvert, 2010). Such developments further influence designers to speculate on the potential impact of synthetic biology (Agapakis 2013), such as in Daisy Ginsberg’s Synthetic Kingdom, which imagines applications to discuss a new form of nature that is created in laboratories. Discoveries in microbiology, particularly in terms of the role of microorganisms in our bodies (Turnbaugh et al., 2007), have further challenged the way we understand the world, providing novel ways in which biotechnology may improve quality of life and wellbeing - such as low tech microbiota transplantations (Gough et al. 2011).

In this paper, we report on the design process of three domestic objects that incorporate living organisms, and which have been exhibited in a festival in the UK. We reflect on what changes in design when we start considering materials that evolve, through time and as part of complex ecosystems, and discuss how engaging with living materials could be considered a shift in traditional design practices. By describing challenges encountered in the process, from legal limitations of taking genetic modified organisms out of the lab, to meeting health & safety standards of an exhibition space, and finding the right living materials to visually represent our concepts, we reflect on current limitations of integrating design in biotechnology development. Despite these constraints, there is a huge value in exploring living organisms as materials for design. Identifying these limitations is the first step in anticipating and redefining future collaborative practices.

Three Concepts

In this speculative project designed for an exhibition space, we attempted to reimagine the context of the home in a not too distant future in which synthetic biology would become commonplace, where microorganisms would be widely recognised as important actors in everyday life, and objects would grow and evolve according to environmental conditions





and levels of care. We developed three concepts. The first is a biological intervention in a kitchen sink (see Figure 1). In this concept, microorganisms living in the drain would act as biosensors, indicating changes in its ecosystem and potential hazards to people around. The organisms indicate the presence of metals such as lead and copper in the water through colour change, signifying that action is necessary.

The second concept corresponds to a set of knives that are embedded in a biological material, which evolves and is tailored to its users (Figure 2). While this material facilitates the knife's cutting function (we can imagine that cutting would happen at the atomic level, with the biologic material breaking the chemical bonds of the food) it also indicates when it comes into contact with a particular substance that is potentially harmful to its user (such as allergens, gluten, sugar or fat concentration). The organisms live on the knife and are fed from organic matter that accumulates on it. Once microorganisms can carry out the cutting function, the form of these knives can be reconsidered.

The final concept corresponds to a textile that changes according to seasons, to its interaction with other microorganisms, and levels of human care (Figure 3). This textile is kept in a generative environment for a period of time. Once its growth is considered satisfactory, it is brought into use, degrading over time. Once degraded, it is taken back to the controlled environment in order to regenerate.



From left to right and top to bottom:

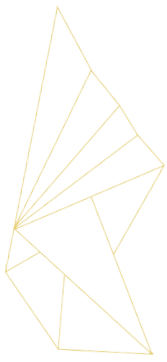
Figure 1. Agar with beer yeasts colonies in a kitchen sink. Photo: Anaïs Moisy

Figure 2. Set of knives embedded in a beer yeast. Photo: Anaïs Moisy

Figure 3. A textile made of natural moss. Photo: Anaïs Moisy

Figure 4. A glass drawer under the sink representing the regeneration space for the fabric. Photo: Anaïs Moisy





We developed these concepts in the form of an installation that was exhibited for three weeks as part of the Design Informatics Pavilion at the Digital Entertainment Festival in Edinburgh, UK. For the exhibition, we combined the concepts in a kitchen scenario. A kitchen counter was mounted with a sink and the set of knives was displayed on the top of it. A glass drawer under the sink was designed to illustrate the regeneration space for the fabric (Figure 4), which would hang on the side of the counter when in use, as one would do with a tea towel. In the following section, we present the design process carried out to represent these concepts, and later discuss limitations and the design practice more broadly.

Designing with Living Organisms

Finding the Right Organism

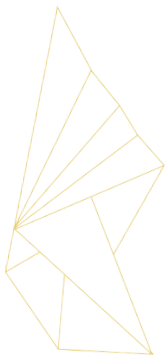
Based at the Edinburgh Genome Foundry, we had access to laboratory facilities and specialists' advice in synthetic biology, and were able to carry out initial experiments. For the sink intervention, we envisioned a culture of yeast that was genetically modified to become a biosensor. Yeast contains a specific promoter called pCUP1, which reacts to metals such as copper, increasing expression of the corresponding gene. This



Figure 5. Colonies of bacteria containing RFP on agar set on a lab sink. Photo: Anaïs Moisy

promoter can be used to control the expression of a reporter gene such as Red Fluorescent Protein (RFP), which can alter the colour of the microorganism when triggered, causing it to appear pink in the presence of high amounts of copper. As such this system can be used as an indicator for water contaminated with high levels of copper, serving as a warning that it should not be consumed. For the purpose of initial visualisations of the concept, the rapid growing bacteria - *Escherichia coli*, modified to contain a red fluorescent protein, was used to produce an initial prototype. We collected a laboratory plate of the bacteria containing RFP and set it on a lab sink in order to produce initial documentation (Figure 5).





Experiments in the lab, however, raised concerns about the prohibition of the exposure of genetic modified organisms (GMOs) in public spaces or non-enclosed biosafety laboratories (see Risk Assessment Challenges subsection). Unable to circumvent this restriction, we looked at microbial alternatives to illustrate our ideas at the final exhibition.

An alternative was to culture microorganisms collected in our environment, e.g. from door handles, tabletops, etc. We cultured a number of samples (Figure 6) as described in the “Searching for colours” section, but this option was ultimately discouraged (see Risk assessment challenges subsection). We also explored different ways of mimicking



Figure 6. Agar plates with growing colonies from a collection of samples (from left to right) : sample collected 2 meters from an outside trash, hand print, two different samples collected in a bathroom, sample collected on a outside wall with moss. Photo: Anaïs Moisy

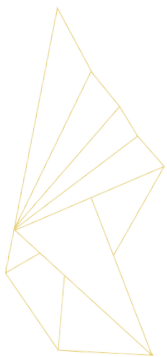


Figure 7. Slime mould living on a piece of cotton fabric. Photo: Anaïs Moisy

the appearance of growing microorganisms with unconvincing results (see Manipulating Form subsection). We finally opted to food grade yeast obtained from beer lees, and subsequently grown in yeast growth media, for the sink and knives concept.

For the textile concept, we considered organisms that would be perceived as familiar and which would be intuitively recognised as objects of attention and care, and opted to use moss plant to represent it. We also looked at possible species that would support the regeneration of the fabric, and opted to use slime mould (Figure 7), or *Physarum polycephalum*, a eukaryotic unicellular organism that is commonly used in art projects.





Dealing with Evolution and Growth

One of our concerns was to guarantee the well-being of the microorganisms with which we were working, and how we would administrate growth over time. Each microorganism requires specific nutrients, which are often mixed into a solution with agar, a substance obtained from algae that is ubiquitous in microbiology. The agar substance can be more or less solid. As we learned in the process, growth can be influenced by the supplementation or restriction of nutrients within the agar solution. It can also be influenced by changes in temperature. Optimised temperatures can accelerate growth - for instance the optimum temperature for E.coli is 37oC (Noor, 2013; Chan et. al, 2006) and 30oC for yeast (White and Munns,1951). Controlling light, pH and interaction with other microorganisms are other important factors. Within the conditions of our exhibition, we predicted that the nutrients would run out and the colonies would stop growing after 3-5 days.

In the laboratory, we cultivated the yeast colonies for 2 to 3 days and then kept them in the fridge (yeast growth at 4oC is negligible). It was however hard to precisely predict how these organisms would grow in the exhibition as conditions would vary, as temperature was not closely controlled and the interactions with the public and invigilators could also affect its state.

Manipulating Form

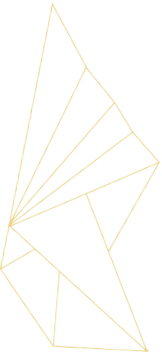
We experimented with different methods to transfer the microorganism into the exhibition sink. One of the challenges was to produce a sample with single colonies equally distributed on its surface. As advised by microbiologists in the lab, the best way to do this was to place glass beads onto a plate (commonly known as a petri dish) and shake them in order to spread microorganisms equally. Developing this method on agar poured directly into the sink was unfeasible.

One technique used in microbiology to isolate single colonies among a population of microorganisms is through a dilution method called 'streaking'. With a sterile inoculation loop, a small sample of the microorganism population is gently smeared on the surface of the agar plate in a zigzag motion, with individual colonies growing along the drawn lines. These streaks, however, did not produce the effect that we were looking for, as they looked designed rather than emergent.

We therefore decided to simply grow yeast on agar plates in 140mm large petri dishes. Once grown, the agar was removed from the plastic petri dish and place it inside the sink, giving the possibility to replace it when dried or contaminated.

For the sink intervention, we cultured beer yeast on an agar plate, and scraped a small sample using an inoculation loop. For this experiment





we used synthetic complete (SC) medium, which is a transparent solution commonly used for culturing yeast. The sample was re-suspended in SC medium and serially diluted by a factor of 1 in 10,000. The diluted yeast was again plated onto the agar, using the glass beading technique to spread colonies evenly on the plate. Finally, we cultured the yeast overnight in a 30oC incubator. The colonies were still very small (1-2mm). Its evolution and growth would therefore be visible over time in the exhibition.

For the knife concept, we used long spread knives that resembled traditional knives, but, with no sharp edges or pointing ends, did not present the cutting feature. The spread knives were placed into glass tubes, which in turn resembled test tubes used in laboratories as well as spice containers found on kitchen counters. The tubes were filled with agar containing yeasts. In our first experiment, we tried mixing the yeast with the molten agar and casting them in the glass tube. We mixed yeast culture, previously grown overnight into molten agar cooled to ~45oC and poured the mixture into the tubes and left to set and grown for 48 hours. Our expectation was that, since yeast can grow in anaerobic conditions, such as in alcohol fermentation processes, it would have no problem growing within more solid agar solution, and this experiment would result in evenly spread round colonies. After 24 hours, however, the agar had hardened and was cracked due to the increased pressure created by the yeast growth, and the substance was therefore pushed outside the tube.

In order to show that the knives were impregnated with biological material, the colonies should grow along the knife on the vertical rather than the horizontal section of the tube (from top to bottom). In order to obtain this result, we needed a different plating technique. Therefore, in our second experiment, we poured molten agar to fill only half of the tube. We closed the tube and let the agar cool down to solidify horizontally (Figure 8). We were then able to plate the yeast on this surface, again using the glass beads. The yeast was cultured with the tubes placed horizontally for 48 hours in a 30oC incubator. When the colony size was big enough to be visible, we filled the rest of the tube

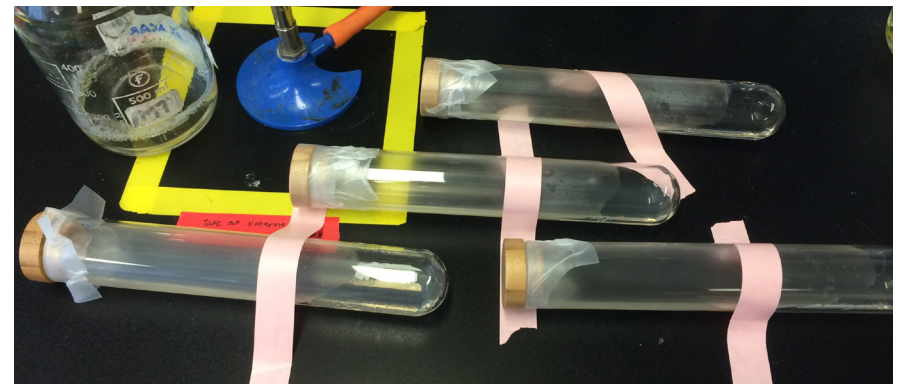
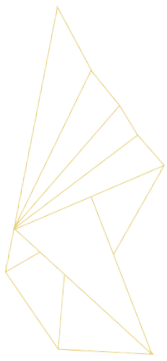


Figure 8. Tubes used for the exhibition containing melted agar left to cool down and solidify horizontally. Photo: Anaïs Moisy





with agar and sealed the top. We reapplied this method on all tubes to be exhibited. When ready, we placed the knives into the agar and sealed the top with parafilm to avoid contamination (Figure 9).

While investigating options for the exhibition, we also looked into ways of mimicking colonies with other substances. We created plates with jelly instead of agar, and sugar sprinkles instead of microorganisms. The instant result was visually close to the initial experiment with the modified red E.coli, but it was hard to prevent the sugar from dissolving in those conditions (Figure 10). We then experimented with spherification, a process used in molecular cooking in order to shape liquid into spheres using sodium alginate and calcium chlorate. We used pink food colouring in this process, which produced more stable, but less convincing results (Figure 11).

Searching Colours

Throughout the process we investigated different ways to explore colour. With GMOs we could easily obtain a specific colour, but once this option was ruled out we were compelled to search for alternatives. In the subsequent experiments, we plated samples of saliva, fingerprints, sediments from showers and an external wall in the search of colourful colonies. By cultivating these samples from the environment we were able to keep the visual impact of living organisms without using GMOs. The samples grew into colonies of different colours: shades of yellow,



Figure 9. Spread knives installed into the agar with parafilm to cover the top to avoid contamination. Photo: Anaïs Moisy

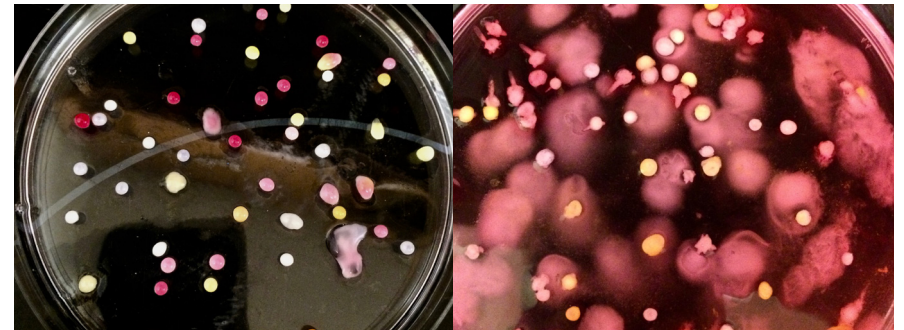


Figure 10. Plates made with jelly and sugar sprinkles. Photo: Anaïs Moisy

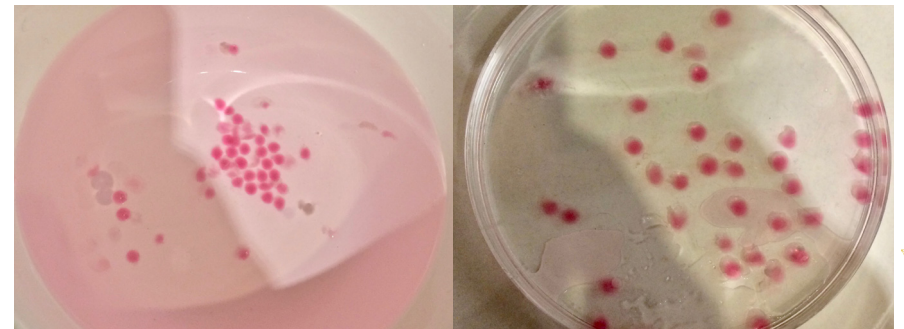
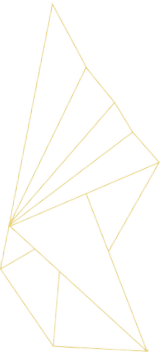


Figure 11. Spherification process. Photo: Anaïs Moisy





orange, white, beige (Figure 12). Although we ultimately decided to use beer yeast in order to avoid time-consuming risk assessment processes, this option remains as an alternative for aesthetic exploration. In the yeast experiments, we repeated it using agar modified with food colouring (Figure 13). Although that produced an effect in the knife tubes, the natural coloured agar produced better results.

Caring for Multiple Species

The textile concept attempted to tell a story of sustainability, circular life cycle and cooperation. As mentioned above, it presented two states: one of use, and one of regeneration. In the exhibition, we designed a sealed glass drawer that was placed underneath the sink to represent a space for regeneration. We initially tried to grow moss onto a fabric surface by using a sample of natural moss and a mixture of buttermilk, water and sugar (Figure 14). In our studio space, however, the mixture grew mouldy within a few days. We finally collected samples of moss from the Water of Leith river bank (Figure 15) and tied it to two pieces of cotton fabric (Figure 16). While one piece was hung on the side of the kitchen counter, as one would hang a tea towel, the other was placed inside the drawer to represent its state of regeneration. The regeneration would be carried out by a eukaryotic organism, commonly referred to as slime mould. In nature, slime mould feeds on microorganisms such as bacteria, yeast, and fungi living on dead vegetation (Allaby, 2013). In our scenario, it would represent the living organism that would ‘clean’ the used towel

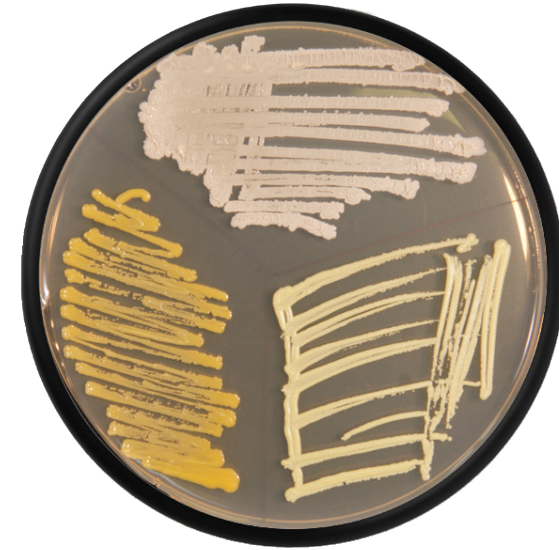
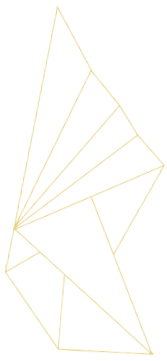


Figure 12. Colonies of different colours made from colonies picked on a plate with microorganisms from a hand. Photo: Anaïs Moisy



Figure 13. Test tubes used in laboratories filled with agar containing yeasts. The middle one coloured with red food colouring. Photo: Anaïs Moisy

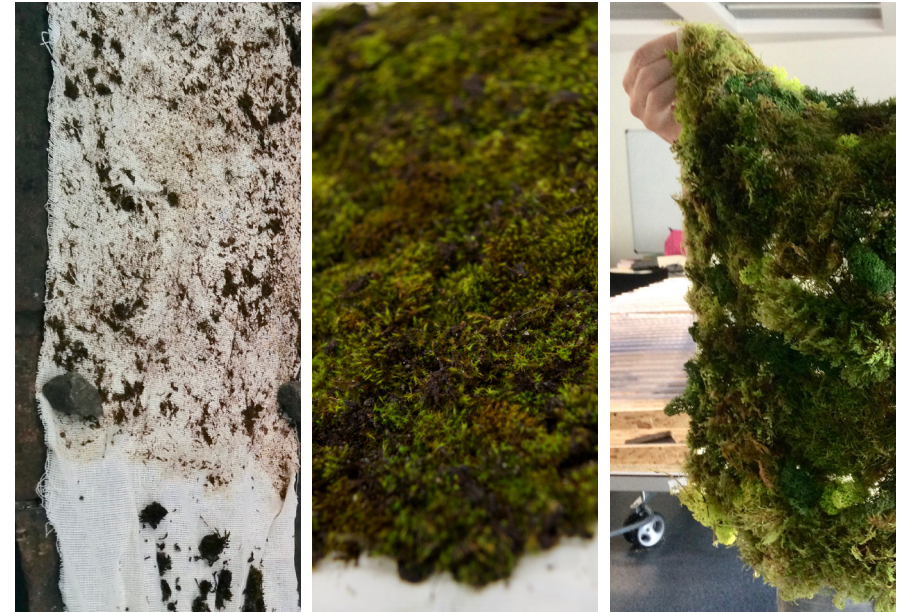




by degrading residue. At the exhibition, it would also degrade samples of agar, yeast and bacteria, which would be replaced if contaminated. The drawer would therefore be both a space of regeneration and recycling.

Inside the drawer, we also placed a bowl of water where dry ice should be placed twice a day (Figure 17). The aim was to both create an effect of fog in the exhibition and to increase concentration of CO₂ (released by the dry ice in the process) to support growth and regeneration of the fabric, as observed by previous research (Tuba 2011). We however did not anticipate that rising levels of CO₂ would be unfavourable to the slime mould (Kamiya 1959), which turned black and eventually stopped growing after a while. The slime mould was also affected by the levels of light in the exhibition (Mayne, 2016). Even when closed, the transparency of the drawer let light through, compromising the growth.

This demonstrates the difficulty of mediating interaction across species. Optimal temperature, humidity, light, air and nutrient conditions must be studied and experimented for a significant period of time, before being able to predict outcomes. Species need to adapt to one another, and this adaptation may still be impossible. Placing them in the same environment does not guarantee that they would interact as expected. This means that designers must be comfortable with longer development processes and outcomes.



From left to right:

Figure 14. Initial experiment to grow moss on fabric. Photo: Shi Hui

Figure 15. Samples of moss from the Water of Leith river bank. Photo: Anaïs Moisy

Figure 16. Samples of moss stapled on a cotton fabric . Photo: Anaïs Moisy

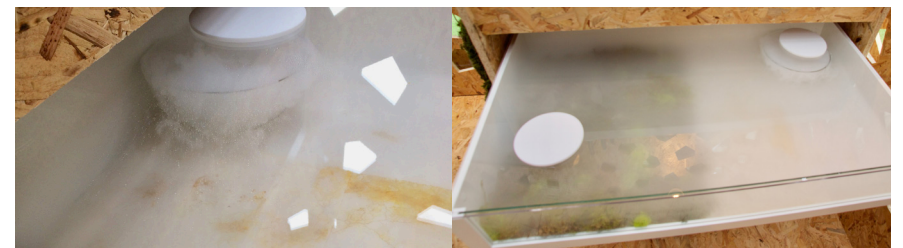
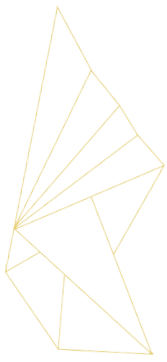


Figure 17. Drawer from the installation, containing a bowl of water where dry ice was placed twice a day. Photo: Anaïs Moisy





Risk Assessment Challenges

As mentioned above, access to genetic modified organisms (GMOs) is restricted to enclosed laboratory facilities, which need to comply with standards that aim to guarantee that the organisms stay within the laboratory or biotechnology production facility and that the health and safety of staff is maintained (see reference GMO Contained Use 2014). At the moment, in order to release GMO's into the environment, researchers must go through an extensive process of authorisation that is carried out at national level (see GMO Deliberate Release 2002). In England & Wales this process is subject to the Secretary of State. In Scotland, it is subject to the GM Inspectorate and Science and Advice for Scottish Agriculture. These restrictions relate to potential risks of unexpected consequences of synthetically modified organisms in the environment, as well as to the interests of companies and particular groups. It finally makes authorisation for small scale projects unfeasible, leaving little space to employ synthetic biology in one-off art or public engagement installations.

Safety measures when working with other kinds of organisms also present a big challenge for designers. As we experimented with culturing microorganisms collected from our environment, we assumed that these organisms would be harmless in an exhibition space too. However, as advised by biologist colleagues, some of these organisms could become

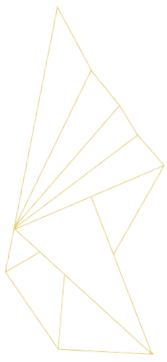
pathogenic in high concentrations, potentially providing some risk to human health. Identifying pathogenic organisms in real-world samples would be a laborious process and without this analysis it would be impossible to ensure that they were safe.

In the School of Biological Sciences at the University of Edinburgh, public engagement work over the last decades has avoided using living organisms due to an overall uncertainty regarding the safety protocols that are in place, and the kinds of risk assessments that are needed.

Furthermore, the agar growth medium was optimal for culturing many types of microorganisms, which could land on its surface finding an appropriate environment to duplicate and grow. Again, in high concentration, these new microorganisms could potentially be dangerous. Therefore, even if using safe microorganisms such as the yeast sample that we ultimately decided to pursue, could not be used in exposed demonstrations.

For the knife concept we opted to seal the tubes with paraffin, in order to avoid other microorganisms landing on the surface and to give the appropriate environment to grow and duplicate. For the sink concept, we first considered covering the plates with a second layer of agar containing no nutrients, which would seal the plates while still maintaining transparency. At this stage we wanted to keep the sink open to preserve the appearance of a real kitchen. The agar however was too





thick and cracked, quickly dried up and even without nutrients, other microorganisms started to grow on the top layer after a few days.

We finally decided to seal the sink. We laser-cut a custom size transparent acrylic top and screwed it onto the sink. With this solution, we restricted access to the organisms for the public, and eliminated the risk of contamination. The top could also be removed in order to clean and replace the sample when required.

Discussion: Design Practice

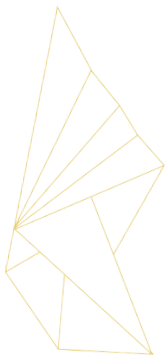
The experiments above demonstrate some challenges of designing with living organisms. Indeed, living organisms cannot be regarded as mere materials for design. In our experiments, they required extra care, attention and commitment. Being accustomed to manipulating raw materials such as wood, acrylic and glass, or computer code and electronics, which all have relatively predictable outcomes, it is hard to avoid particular assumptions towards things that we design with. In our case, we could not help treating living organisms as materials when searching for particular colours for example. In the case of the textile experiment, more commitment towards understanding the life cycles of the species was necessary. Outcomes when designing with

living organisms are not straightforward. Living organisms are clearly more sensitive to environmental conditions than wood and plastics. And even when these conditions are taken into account, and environment regulators are incorporated in the design, organisms may still not react as expected. As brewers have long realised (AAM, 2014) the well-being of microorganisms is essential for them to grow and contribute to the design in the best way possible. Learning about optimal conditions, life cycles and interaction with other living organisms, however, takes time and dedication.

During our experiments we often wondered how our perception of the organisms with which we were working would have changed if we were able to incorporate our genetic modified organisms in our exhibit. Synthetic biology tends to regard living organisms in objective, often utilitarian ways (ETC Group, 2014; Cameron et al, 2015) - assumptions that are embedded for instance in its language (Calvert and Frow, 2015) such as in the term chassis, which is used in synthetic biology to refer to a cell. It can also be seen in common practices such as DNA replication in E.coli. Even if legal restrictions were not taken into account such assumptions are misleading (Catts and Zurr, 2008). If they were true, processes of designing with living organisms could be radically shortened, but forms of life are rather chaotic and interdependent.

As Biodesign becomes more popular, there remains the question of whether designers will become familiar with living forms through their





metier, as micro-brewers and gardeners do, to the point of intimately recognising responses of microorganisms, or if they will treat living organisms as programmable material, expecting straightforward outcomes as synthetic biology tends to do. While narratives of the future of synthetic biology promise that the latter will be true (Barret et al 2006), traditional education in design, where materials such as wood and resin are manipulated directly and low tech prototyping tools such as Arduino are the norm, suggests that the first will ultimately prevail.

Practices in biotechnology, however, also need to adapt to accommodate design as a discipline. In our process we encountered a number of limitations that resulted from applying traditional design practices into a context that has limitations of its own. Restrictions in synthetic biology has many motivations, from a way to prevent unexpected consequences of its outcomes on local environments and social context, to a way of protecting interests of particular groups and corporations.

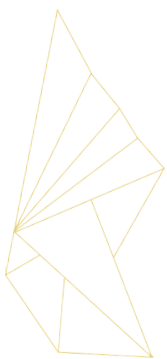
There is however a huge value in exploring living organisms as materials for design. Perhaps one way to integrate design practices in the biotechnology process and vice versa without loosening up regulations that are important to prevent negative outcomes of genetic modification is to define standards of safety where some organisms and practices are validated and standards are integrated in design, rather than in policy control.

From our experience, the collaboration between designers and scientists can help both disciplines. It helps designers to understand practices and become more aware of broader effect of working with biomaterials and helps biologists reflect on the impact of their research when that is incorporated into the home environment.

Acknowledgements

We would like to offer huge thanks to Jamie Auxillos for her support with the biological experiments, her scientific expertise. Also, thanks to Shi Hui for being involved in the ideas development, Mark Kobine for his support and help in the design of the kitchen, and finally Erika Szymanski, Alba Ubide and Roy Walker, for their support and advice in this project. Thank you to James W Bryson, Jamie Auxillos , Mark Kobine and Roy Walker for proofreading.





References

Agapakis, C. M. (2013). Designing synthetic biology. *ACS synthetic biology*, 3(3), 121-128.

AAM - American Academy of Microbiology Report (2014). If Yeast Ain't Happy, Ain't Nobody Happy. <https://tapsclub.files.wordpress.com/2014/06/iftheyeastainthappy.pdf>

Allaby, M., & Park, C. (Eds.). (2013). *A dictionary of environment and conservation*. OUP Oxford, 395.

Antonelli, P. (2012). Vital design. In: *Bio Design: Nature, Science, Creativity*.

Barrett, C. L., Kim, T. Y., Kim, H. U., Palsson, B. Ø., & Lee, S. Y. (2006). Systems biology as a foundation for genome-scale synthetic biology. *Current opinion in biotechnology*, 17(5), 488-492.

Calvert, J. (2010). Synthetic biology: constructing nature?. *The sociological review*, 58(s1), 95-112.

Calvert, J & Frow, E (2015). 'The Synthetic Yeast Project as a Topic for Social Scientific Investigation' *Macquarie Law Journal*, vol 15, no. 2015, 1, pp. 27-37.

Cameron, D. E., Bashor, C. J., & Collins, J. J. (2014). A brief history of synthetic biology. *Nature Reviews Microbiology*, 12(5), 381-390.

Catts, O., & Zurr, I. (2008). The ethics of experiential engagement with the manipulation of life. *Tactical biopolitics: Art, activism, and technoscience*, 125-42.

Chan, J. , Davis, C., & Jokic, I. (2006). Influences of growth temperature and preparation of competent cells on efficiency of chemically-induced transformation in Escherichia coli DH5α. *J. Exp. Microbiol. Immunol*, 9, 92-96.

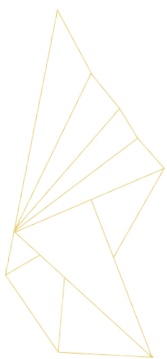
ETC Group (2014). Video: What is Synthetic Biology? http://www.etcgroup.org/synthetic_biology_explained

Ginsberg, A. D., Calvert, J., Schyfter, P., Elfick, A., and Endy, D. (2014) *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature*, MIT Press, Cambridge, MA.

GMO Contained Use (2014) *The Genetically Modified Organisms (Contained Use) Regulations 2014*. Downloaded from: <http://www.hse.gov.uk/pubns/priced/l29.pdf>

GMO Deliberate Release (2002) *Genetically Modified Organisms (Deliberate Release) Regulations 2002*. For England and Wales: <http://>





www.legislation.gov.uk/uksi/2002/2443/pdfs/uksi_20022443_en.pdf
For Scotland: http://www.legislation.gov.uk/ssi/2002/541/pdfs/ssi_20020541_en.pdf

Gough, E., Shaikh, H., & Manges, A. R. (2011). Systematic review of intestinal microbiota transplantation (fecal bacteriotherapy) for recurrent *Clostridium difficile* infection. *Clinical infectious diseases*, 53(10), 994-1002.

Johung, J. (2016). "Speculative Life: Art, Synthetic Biology and Blueprints for the Unknown." *Theory, Culture & Society* 33(3): 175-188.

Kamiya, N. (1959). *Protoplasmic Streaming*. Springer Vienna, 116.

Mayne, R. (2016). Biology of the *Physarum polycephalum* plasmodium: Preliminaries for unconventional computing. In *Advances in Physarum Machines: Sensing and computing with slime mould (Vol.21)* (pp. 3-22). Springer International Publishing.

Noor, R., Islam, Z., Munshi, S. H., & Rahman, F. (2013). Influence of temperature on *Escherichia coli* growth in different culture media. *J Pure Appl Microbiol*, 7(2), 899-904.

Tuba, Z., Slack, N. G., & Stark, L. R. (Eds.). (2011). *Bryophyte ecology and climate change*. Cambridge University Press, 65-66.

Turnbaugh, P. J., Ley, R. E., Hamady, M., Fraser-Liggett, C., Knight, R., & Gordon, J. I. (2007). The human microbiome project: exploring the microbial part of ourselves in a changing world. *Nature*, 449(7164), 804

White, J., & Munns, D. J. (1951). Influence of temperature on yeast growth and fermentation. *Journal of the Institute of Brewing*, 57(4), 280-284.

